# PERFORMANCE ANALYSIS OF NOMA-V2V COOPERATIVE SYSTEMS WITH OUTDATED CSI AND IMPERFECT SIC

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***Title:***
*Phân tích hiệu năng hệ thống V2V sử dụng NOMA trong điều kiện CSI và SIC không hoàn hảo*

**Từ khóa:**
*Đa truy nhập không trực giao (NOMA), vehicle-to-vehicle (V2V), SIC không hoàn hảo, Trễ thông tin trạng thái kênh (Outdated CSI), Hiệu năng hệ thống.*

***Keywords:***
*NOMA-V2V cooperative communication, Imperfect SIC, Outdated CSI, System performance.*

**TÓM TẮT:** *Trong bài báo này đề xuất mô hình hợp tác vehicle-to-vehicle (V2V) sử dụng phương thức đa truy nhập không trực giao (NOMA: non-orthogonal multiple access). Hiệu năng của hệ thống được xem xét trong điều kiện trễ thông tin trạng thái kênh (CSI: channel state information) và khử nhiễu liên tiếp (SIC: successive interference cancellation) không hoàn hào. Đề xuất phương thức phân bổ công suất tối ưu để đạt được cực đại tốc độ truyền. Để đánh giá hiệu năng hệ thống đề xuất chúng tôi xác định các biểu thức tốc độ truyền và xác suất dừng hoạt động hệ thống, ngoài ra so sách phương thức NOMA với đa truy nhập trực giao (OMA: orthogonal multiple access) nhằm chỉ ra ưu điểm của hệ thống đề xuất. Từ kết quả bài báo có thể làm cơ sở lý thuyết cho việc triển khai hệ thống hợp tác giữa các phương tiện giao thông hiện nay..*

**ABSTRACT:** *In this paper, a non-orthogonal multiple access vehicle-to-vehicle (NOMA-V2V) cooperative system model is proposed. The outdated channel state information (CSI) is derived based on the conventional channel model. The residual interference is derived using outdated CSI to characterize the degree of successive interference cancellation (SIC), i.e. imperfect SIC. A power allocation scheme is proposed to maximize the sum achievable rate of the NOMA-V2V cooperative system under consideration of residual interference. Achievable rates and outage probabilities of the NOMA-V2V and OMA-V2V cooperative systems are derived. The effects of the power allocation coefficient, imperfect SIC, transmission power, and the distance between transmitting and receiving ends on the achievable rates and outage probabilities are analyzed for the NOMA-V2V cooperative system. These results are compared with the OMA-V2V cooperative system. It provides theoretical guidance for V2V cooperative networks to choose which multiple access method.*

## 1. Introduction

Vehicle-to-vehicle (V2V) communication has attracted widespread attention in the Beyond 5G (B5G) and the sixth Generation (6G) communication systems V2V communication can not only improve the quality of road traffic, reduce accidents, and save energy, but also promote the development of new driverless. Non-orthogonal multiple access (NOMA) technology is considered one of the key technologies to meet the next generation of mobile communications with good overload performance. In power-domain NOMA, users are allocated different power coefficients according to their channel conditions. The power allocation between users is essential to maximize the full potential of NOMA. A power allocation method of the superimposed signal was proposed in, which maximizes the achievable rate of the secondary user under the quality of service (QoS) constraint of the primary user. To further improve the performance of NOMA, the power allocation system was proposed in [6] to maximize fairness for paired user group consisting of two users under half-duplex mode. By combining NOMA and vehicle to everything (V2X) can mitigate resource conflicts, improve spectral efficiency, and reduce latency. NOMA performs a successive interference cancellation (SIC) technology at the receiver to achieve multi-user detection. The basic idea of SIC techniques adopts step-by-step interference elimination strategies, the multiple access interference generated by the user signal is subtracted from the received signal, and judge the remaining users again. Therefore, it is important to investigate the effect of imperfect SIC on the NOMA-V2V strategy. However, there is little work investigate the influences of imperfect SIC on NOMA-V2V cooperative systems.

To make up for these deficiencies, we investigate the NOMA-V2V cooperative communication system based on 3D two-cylinder channel models under considering outdated CSI and different degree SIC. The large-scale fading and small-scale fading are considered on the V2V links. Two power allocation schemes of NOMA-V2V and OMA-V2V cooperative systems are proposed, respectively to optimize system performances. And the achievable rates and outage probabilities are analyzed of NOMA-V2V and OMA-V2V cooperative systems. Main contributions of the paper are summarized as follows.

A NOMA-V2V cooperative communication systems model is proposed. The outdated CSI is considered based on a two-cylinder channel model. And the residual interference is derived using outdated CSI to characterize the degree of SIC.

To further optimize system performance with outdated CSI, a power allocation scheme considering residual interference is proposed to maximum the sum achievable rate of NOMA-V2V cooperative system. The corresponding power allocation scheme of OMA-V2V cooperative system is proposed.

The effects of power allocation factors, transmission power, residual interference, and the distance between transmitting and receiving ends on achievable rates and outage probabilities are analyzed for NOMA-V2V cooperative. And these results are compared with the OMA-V2V cooperative system.

The remainder of this paper is organized as follows. Section II describes the system model of the NOMA-V2V cooperative communication. Section III presents the outdated CSI and imperfect SIC for the NOMA-V2V cooperative system. Section IV presents the achievable rate of the cooperative system and power allocation schemes of NOMA-V2V and OMA-V2V cooperative systems. Section V analyzes the outage probabilities of the NOMA-V2V and OMA-V2V cooperative systems. Some simulation results and analysis are performed in Section VI. Finally, this article is summarized in Section VII.

## 2. Theoretical framework and Methods

A NOMA-V2V communication system aided with a vehicle relay is considered as illustrated in Fig. 1. Two time-slots are required to transmit a set of data in the system. In the first time-slot, the source vehicle ( $V_S$ ) uses the NOMA technique to transmit the signals $x_S$ composited by $S_1$ and $S_2$ to the destination vehicle ( $V_D$ ) and vehicle relay ( $V_R$ ) by assigning the power allocation coefficients $\alpha^{NOMA}$ and $(1-\alpha^{NOMA})$ , respectively.

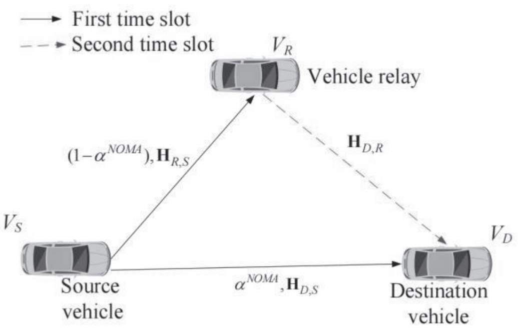



Fig.1 A system model for NOMA-V2V cooperative communication.

The signal received at the node $V_D$ can be indicated as

$$y_{S-D} = \mathbf{H}_{D,S}(\sqrt{\alpha^{NOMA} P_S} S_1 + \sqrt{(1-\alpha^{NOMA}) P_S} S_2) + n_D \tag{1}$$

The signal received at the node $V_R$ is indicated as

$$y_{S-R} = \mathbf{H}_{R,S}(\sqrt{(1-\alpha^{NOMA}) P_S} S_2 + \sqrt{\alpha^{NOMA} P_S} S_1) + n_R \tag{2}$$

In the second time-slot, since $V_R$ works in the decode-and-forward (DF) mode in this system, it decodes the received signal. Then $V_R$ send $S_2$ to $V_D$ . The signals received at $V_D$ can be obtained as

$$y_{R-D} = \mathbf{H}_{D,R}\sqrt{P_R(1-\alpha^{NOMA})} S_2 + n_D \tag{3}$$

where $\mathbf{H}_{D,S}$ $\mathbf{H}_{R,S}$ and $\mathbf{H}_{D,R}$ are the channel matrices, and $P_i$ is the transmission power at the node $i$ . $N$ is minimum value of the number of antennas for the transmitter and receiver. And $\Lambda_{i,j} = \frac{P_j \left\|\mathbf{H}_{i,j}\right\|_F^2}{N N_0}$ , $\|\mathbf{X}\|_F^2$ denotes the Frobenius norm of $\mathbf{X}$ . The variables $n_i$ is the Additive White Gaussian Noise at node $i$ with the distribution $CN(0, N_0)$ .

The received signal to interference plus noise ratio (SINR) at $V_S$ for $S_1$ can be expressed as

$$\gamma_{S-D} = \frac{\alpha^{NOMA}\Lambda_{D,S}}{(1-\alpha^{NOMA})\Lambda_{D,S}+1} \tag{4}$$

The signal $S_2$ is decoded at $V_R$ by using the SIC method, i.e. $S_1$ is decoded firstly (by considering $S_2$ as noise) and removed from the received signal, then $S_2$ is decoded. According, the received SINR at $V_R$ for $S_2$ in the first time-slot can be expressed as

$$\gamma_{S-R} = \frac{(1-\alpha^{NOMA})\Lambda_{R,S}}{\alpha^{NOMA}\Lambda_{R,S}+1} \tag{5}$$

On the other hand, the received signal with less power is transmitted by the relay link. Thus, only $S_2$ is transmitted by $V_R$ in the second time-slot, the SINR at $V_D$ for $S_2$ is expressed as

$$\gamma_{R-D} = (1-\alpha^{NOMA})\Lambda_{D,R} \tag{6}$$

## 3. Results and Discussion

### *3.1. Outdated CSI and Imperfect SIC*

Due to the feedback delay and fast time-varying characteristics of V2V communication systems, the CSI may be outdated in V2V communications. The outdated CSI used for the achievable rate may differ from the actual values $h_{mn}$, giving

$$h_{mn}(t) = R_{mn,\tilde{m}\tilde{n}}(\tau)\tilde{h}_{mn}(t) + \sqrt{1+R^2_{mn,\tilde{m}\tilde{n}}(\tau)}w_{mn}(t),$$

$w_{mn}(t)$ is circularly symmetric complex Gaussian random variables having the same variance as $\tilde{h}_{mn}$. $R_{mn,\tilde{m}\tilde{n}}$ is the correlation coefficient between the outdated channel impulse response and the accurate channel impulse response, can be expressed as

$$R_{mn,\tilde{m}\tilde{n}}(\tau) \approx \frac{I_0\left(\sqrt{x_{DB}^2+y_{DB}^2}\right)I_0\left(\sqrt{z_{DB}^2+w_{DB}^2}\right)}{I_0(k_T)I_0(k_R)} \times e^{-j2\pi\tau D/c_0}\frac{\cos\left[\frac{2\pi}{\lambda}\varepsilon_T^{(p)}(m-\tilde{m})\delta_{Tz}\right]}{1-\left[\frac{4\varepsilon_T^{(p)}(m-\tilde{m})\delta_{Tz}}{\lambda}\right]^2}\frac{\cos\left[\frac{2\pi}{\lambda}\varepsilon_R^{(q)}(n-\tilde{n})\delta_{Rz}\right]}{1-\left[\frac{4\varepsilon_R^{(q)}(n-\tilde{n})\delta_{Rz}}{\lambda}\right]^2} \quad (7)$$

where the variables $x_{DB}$, $y_{DB}$, $z_{DB}$ and $w_{DB}$ as:

$$x_{DB} \approx j2\pi(m-\tilde{m})\delta_{Tx}/\lambda + j2\pi\tau f_{T\max}\cos\gamma_T + k_T\cos\mu_T \quad (8)$$

$$y_{DB} \approx j2\pi(m-\tilde{m})\delta_{Ty}/\lambda + j2\pi\tau f_{T\max}\sin\gamma_T + k_T\sin\mu_T \quad (9)$$

$$z_{DB} \approx j2\pi(n-\tilde{n})\delta_{Rx}/\lambda + j2\pi\tau f_{R\max}\cos\gamma_R + k_R\cos\mu_R \quad (10)$$

$$w_{DB} \approx j2\pi(n-\tilde{n})\delta_{Ry}/\lambda + j2\pi\tau f_{R\max}\sin\gamma_R + k_R\sin\mu_R \quad (11)$$

where $I_0(\cdot)$ represents the first class of zero-order modified Bessel function, $k_i$ represents the diffusion factor of the number of scatterers around the mean value, $\mu_i \in [-\pi,\pi)$ is the average value of the distribution angles of the scatterers in the x-y plane, $\delta_{Tx} = \delta_T\cos\psi_T\cos\theta_T$, $\delta_{Ty} = \delta_T\cos\psi_T\sin\theta_T$, $\delta_{Tz} = \delta_T\sin\psi_T$, $\delta_{Rx} = \delta_R\cos\psi_R\cos\theta_R$, $\delta_{Ry} = \delta_R\cos\psi_R\sin\theta_R$, $\delta_{Rz} = \delta_R\sin\psi_R$. $\delta_T$ and $\delta_R$ represent the distance between two adjacent antennas, Tx and Rx. $\varepsilon_T^{(p)}$ and $\varepsilon_R^{(q)}$ denotes the non-negative maximum elevation of the scatterers around Tx and Rx. Thus, the outdated channel matrix can be expressed as $\tilde{\mathbf{H}}(t) = \left[\tilde{h}_{mn}(t)\right]_{L_R\times L_T}$. Similarly, the outdated channel status information can captures all large-scale fading effects including path loss and shadowing between nodes, and can be obtained as

$$PL = 20\log_{10}\left(\frac{4\pi}{\lambda}\right) + 20\log_{10}(d) + X_\sigma \quad (12)$$

where $\lambda$ is wavelength. $d$ denotes the distance between nodes. $X_\sigma$ denotes the Gaussian random with variance 0 and standard variance 3dB.

Normally, due to the significant fading of the channels or the channel estimation error, the SIC causes a performance failure. Considering the error propagation in the SIC eliminator, remove the signal from the receiver $\xi+1$ to the receiver $\Xi$ ,and get

$$\tilde{y}_\xi = \underbrace{\sum_{i=1}^{\xi-1}\sqrt{\alpha_i P g_\xi}x_i}_{\text{interference}} + \underbrace{\sum_{i=\xi+1}^{\Xi}\sqrt{\alpha_i P\left(g_\xi - \tilde{g}_\xi\right)}x_i}_{\text{imperfect SIC}} + \underbrace{\sqrt{\alpha_\xi P g_\xi}x_\xi}_{\text{expect the signal}} + \underbrace{n_\xi}_{\text{noise}}$$

(13)

where $x_i$ is the data of the receiver $i$, $\alpha_i$ is the power distribution factor allocated to the receiver $i$, $P$ is the total transmission power, and the variables $n_i$ is the Additive White Gaussian Noise and $\tilde{g}_\xi$ represents the outdated channel status

Considering the outdated CSI model, SINR received at the receiver $\xi$ can be expressed as

$$SINR_\xi = \frac{\alpha_\xi \rho g_\xi}{\sum_{i=1}^{\xi-1} \alpha_i \rho g_\xi + \sum_{i=k+1}^{\Xi} \alpha_i \rho r + 1} \quad (14)$$

where $\rho_i = \frac{P_i}{N_0}$ represents the transmission SNR. And $r = \left(g_\xi - \tilde{g}_\xi\right)$ represents residual interference.

### *3.2. Achievable Rate and Power Allocation*

The transmission links consists of $V_S \to V_R$, $V_S \to V_D$ and $V_R \to V_D$. $C_{S-R}^{1,NOMA}$ and $C_{S-D}^{1,NOMA}$ are the achievable rate of $V_S \to V_R$ and $V_S \to V_D$ in the first time-slot, respectively. $C_{R-D}^{2,NOMA}$ is the achievable rate of the $V_R \to V_D$ in the second time-slot.

$C_{S-D}^{sum,NOMA}$ is the sum achievable rate of $V_S \to V_R \to V_D$ and $V_S \to V_D$ in the NOMA system. $C_{S-D}^{sum,NOMA}$ can be obtained as

$$\begin{aligned} C_{S-D}^{sum,NOMA} &= \min\left\{C_{S-R}^{1,NOMA}, C_{R-D}^{2,NOMA}\right\} + C_{S-D}^{1,NOMA} \\ &= \min\left\{\frac{1}{2}\log_2\left(1+\tilde{\Gamma}_{S-R}^{1,NOMA}\right), \frac{1}{2}\log_2\left(1+\tilde{\Gamma}_{R-D}^{2,NOMA}\right)\right\} \\ &\quad + \frac{1}{2}\log_2\left(1+\tilde{\Gamma}_{S-D}^{1,NOMA}\right) \end{aligned} \quad (15)$$

where

$$\tilde{\Gamma}_{S-R}^{1,NOMA} = \frac{(1-\alpha^{NOMA})\rho_s g_{R,S}}{r\alpha^{NOMA}\rho_S + 1} \quad (16)$$

$$\tilde{\Gamma}_{S-D}^{1,NOMA} = \frac{\alpha^{NOMA}\rho_S g_{D,S}}{(1-\alpha^{NOMA})\rho_S g_{D,S} + 1} \quad (17)$$

$$\tilde{\Gamma}_{R-D}^{2,NOMA} = (1-\alpha^{NOMA})\rho_R g_{D,R} \quad (18)$$

and $r = \left(g_{R,S} - \tilde{g}_{R,S}\right)$.

In order to optimize the power allocation coefficient $\alpha$ such that is $C_{S-D}^{sum,NOMA}$ maximum under the constraint of meeting the minimum QoS requirement of the $C_{S-R}^{1,NOMA}$, $C_{S-D}^{1,NOMA}$ and $C_{R-D}^{2,NOMA}$. This problem can be formulated as

$$\begin{aligned} &\underset{\alpha}{Max}\ C_{S-D}^{sum,NOMA} \\ &\quad \text{C1}: 0 < \alpha^{NOMA} < 1 \\ &\quad \text{C2}: \min\left\{C_{S-R}^{1,NOMA}, C_{R-D}^{2,NOMA}\right\} \ge C_{\text{target}} \\ &\quad \text{C3}: C_{S-D}^{1,NOMA} \ge C_{\text{target}} \end{aligned} \quad (19)$$

where $C_{\text{target}} \in (0,\infty)$ is the minimum achievable rate for the system.

The (19) can be derived as

$$\begin{aligned} &\underset{\alpha}{Max}\ C_{S-D}^{NOMA} \\ &\quad \text{C1}: 0 < \alpha^{NOMA} < 1 \\ &\quad \text{C2}: \frac{\rho_s g_{R,S} - \zeta}{\zeta r \rho_S + \rho_s g_{R,S}} \ge \alpha^{NOMA} \\ &\quad \text{C3}: \frac{\rho_s g_{D,R} - \zeta}{\rho_s g_{D,R}} \ge \alpha^{NOMA} \\ &\quad \text{C4}: \frac{(1+\rho_S g_{D,S})\zeta}{(1+\zeta)\rho_S g_{D,S}} \le \alpha^{NOMA} \end{aligned} \quad (20)$$

where $\zeta = 2^{2C_{\text{target}}} - 1$. It can be found that Eqn. (20) is an infeasible problem and there is an outage, if at least one of the following events occurs: (i) $\min\left\{\frac{\rho_s g_{R,S} - \zeta}{\zeta r \rho_S + \rho_s g_{R,S}}, \frac{\rho_s g_{D,R} - \zeta}{\rho_s g_{D,R}}\right\} < 0$, in this case, C2 and C3 are not satisfied. (ii) $\frac{(1+\rho_S g_{D,S})\zeta}{(1+\zeta)\rho_S g_{D,S}} > 1$, in this case the intersection of C1 and C4 are empty. Otherwise, (20) is a feasible problem. C2 and C3 and C4 can be merged to obtain the compact form as

$$\begin{aligned} &\underset{\alpha}{Max}\ C_{S-D}^{sum,NOMA} \\ &\frac{(1+\rho_S g_{D,S})\zeta}{(1+\zeta)\rho_S g_{D,S}} \le \alpha^{NOMA} \le \min\left\{\frac{\rho_S g_{R,S} - \zeta}{\zeta r \rho_S + \rho_S g_{R,S}}, \frac{\rho_R g_{D,R} - \zeta}{\rho_R g_{D,R}}\right\} \end{aligned}$$

(21)

When $0 < \alpha^{NOMA} \le \frac{(1+\rho_S g_{D,S})\zeta}{(1+\zeta)\rho_S g_{D,S}}$, the object function $C_{S-D}^{sum,NOMA}$ is a increasing function, and it becomes a decreasing function when

$$\frac{(1+\rho_S g_{D,S})\zeta}{(1+\zeta)\rho_S g_{D,S}} < \alpha^{NOMA} \le \min\left\{\frac{\rho_S g_{R,S}-\zeta}{\zeta r\rho_S + \rho_s g_{R,S}}, \frac{\rho_R g_{D,R}-\zeta}{\rho_R g_{D,R}}\right\}$$

. Therefore, the optimal value of $\alpha^{NOMA}$ is chosen as

$$\alpha^{NOMA} = \frac{(1+\rho_S g_{D,S})\zeta}{(1+\zeta)\rho_S g_{D,S}} \tag{22}$$

### 3.3. Outage Probability

It is defined that the achievable rate cannot meet a specific expectation threshold and the system experiences disruption. If the achievable rate for the $V_S$ transmits its own data to the $V_R$ is less than minimum desired rate $C_{\text{target}}$, the system undergoes an outage state. The probability of the NOMA and OMA system can be computed as

$$P^{NOMA} = P(C_{S-R}^{1,NOMA} < C_{\text{target}}) \cup P(C_{R-D}^{2,NOMA} < C_{\text{target}}) \cup P(C_{S-D}^{1,NOMA} < C_{\text{target}}) \tag{23}$$

$$P^{OMA} = P(C_{S-R}^{1,OMA} < C_{\text{target}}) \cup P(C_{R-D}^{2,OMA} < C_{\text{target}}) \cup P(C_{S-D}^{1,OMA} < C_{\text{target}}) \tag{24}$$

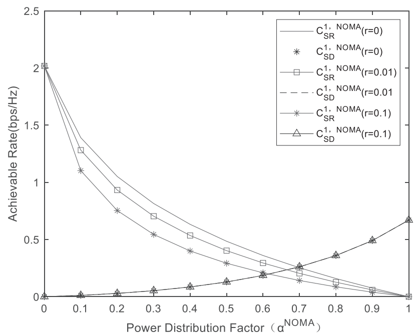
where $C_{\text{target}}$ is the minimum desired rate.

### 3.4. Simulation Results and Analysis

In this section, some simulation results on NOMA-V2V cooperative system performances are presented. And the simulation parameters are listed in Table 2 to guarantee the suitable communication environment.

**Table 2** Simulation parameter values

| Parameter | Definition | Value |
|---|---|---|
| $f_c$ | The carrier frequency | 5.9GHz |
| $R$ | The cylinder radius | 20m |
| $L$ | The number of vehicle antennas | 2 |
| $P, Q$ | The number of effective scatterers on the surface of the two cylinders for the links $V_S-V_D$, $V_S-V_R$ and $V_R-V_D$ | 110 |
| $\theta, \varphi$ | The azimuth and elevation angles of the antenna array at the $V_S$, $V_D$ and $V_R$ | 0 |
| $v$ | Vehicle movement speed | 10m/s |
| $\Upsilon$ | Direction of vehicle movement | π/2 |
| $d$ | The antenna distance | $\lambda$ |



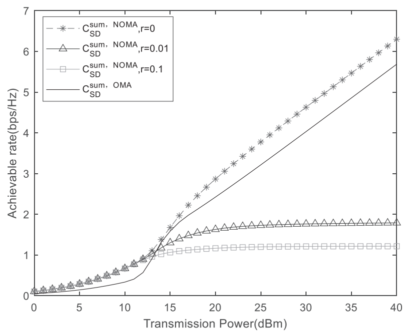



*Fig. 3 The relationship between achievable rates and power allocation factors of NOMA-V2V cooperative system.*

*Fig. 4 The relationship between achievable rate and transmission power under different degrees of residual interference.*

Fig. 3. depicts the achievable rates of power allocation coefficient $\alpha^{NOMA}$ with different degrees of residual interference $r$ for NOMA-V2V cooperative system. It is shown that as the residual interference increases from 0 to 0.1, the achievable rate of the $V_S - V_R$ link is significantly reduced, but it has little effect on the achievable rate of the $V_S - V_D$ link. This is because the NOMA scheme used performs SIC at $V_R$. Thus the residual interference has less effect on the $V_D$. It is also can be seen that as the power allocation coefficient $\alpha^{NOMA}$ increases, the achievable rate of the $V_S - V_D$ link is increasing, while the achievable rate of the $V_S - V_R$ link is decreasing.

Fig. 4 depicts the sum achievable rates of NOMA-V2V cooperative system with different degrees of residual interference and OMA-V2V cooperative system. It is found that when residual interference r=0 and the transmission power is less than 14dBm, the sum achievable rate of NOMA-V2V cooperative system outperforms that of OMA-V2V system. However, with the increasing of residual interference and transmission power, the achievable rate of the OMA-V2V system will outperform that of the NOMA-V2V system. Moreover, it also shows that residual interference has no effect on the sum achievable rate of NOMA-V2V system when the transmission power is less than 14dBm, and has a large effect on the achievable rate of NOMA-V2V with higher transmission power.

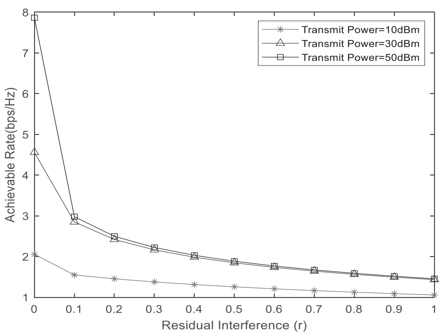



*Fig. 5 The relationship between the residual interference and the achievable rate*

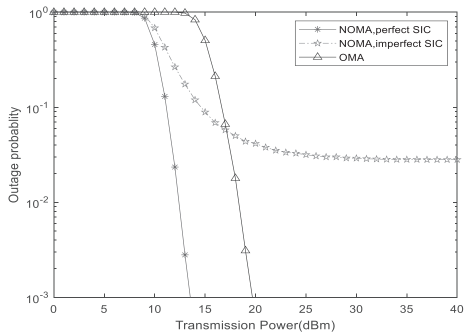



*Fig. 6 The relationship between outage probability and transmission power.*

Fig. 5 shows the achievable rate of the residual interference with different transmission powers for NOMA-V2V cooperative system. In this paper, three different transmission powers of 10dBm, 30dBm and 50dBm are taken for simulation analysis. It can be observed that with the increasing of transmitting power, the sum achievable rate of the system increases. And with the increasing of residual interference, the sum achievable rate decreases. As the transmission power increases, the influence of residual interference on the achievable rate becomes larger, especially when the residual interference varies between 0 and 0.1. This effect decreases as the residual interference coefficient increases. This is because when the residual interference is too large, the effect of the transmission power on the achievable rate of the NOMA-V2V system becomes not obvious.

Fig. 6 shows the outage probabilities of different transmission powers with NOMA-V2V and OMA-V2V cooperative systems. It is found that the outage performance of NOMA-V2V cooperative system with perfect SIC, i.e., the residual interference is 0 is better than that of imperfect SIC system and OMA-V2V cooperative system. When the transmission power is small, the outage performance of NOMA-V2V cooperative system with imperfect SIC outperforms OMA-V2V cooperative system. And with the increasing of transmission power, the outage performance of OMA-V2V cooperative system becomes better. It can be concluded that the outage performance of NOMA-V2V system does not always outperform OMA-V2V system, but also limited by the imperfect SIC, which increases the risk of outage.

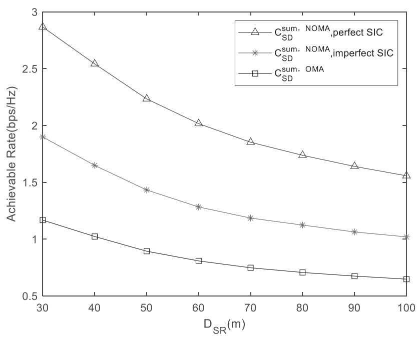



*Fig. 7 (a) The transmission power* $P_S = P_R = 5\text{dBm}$

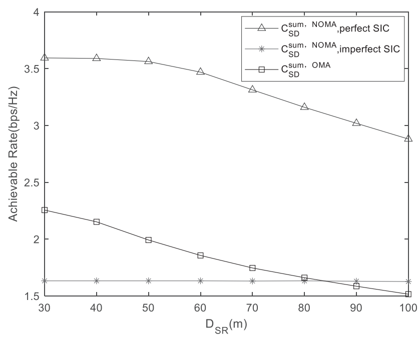



*Fig. 7 (b) The transmission power* $P_S = P_R = 20\text{dBm}$

Fig. 7 (a), (b) shows the relationships between the sum achievable rate and the distance of $V_S - V_R$ for NOMA-V2V and OMA-V2V cooperative systems. The distance between $V_S$ and $V_R$ is used to represent the influence of the distance between transmitting and receiving ends on the achievable rate. From Figs. 7(a) and 7(b), it can be seen that as the distance of $V_S - V_R$ increases, the achievable rate decreases. This is because that the impact of the large-scale fading is significant to channel gains. And, the achievable rate of the NOMA-V2V system cooperative with prefect SIC outperforms that with imperfect SIC. From Fig. 7(a), it can be seen that with the distance increases, the achievable rates of NOMA system with perfect and imperfect SIC always outperforms OMA system when the transmission power is 5dBm. From Fig. 7(b), it can be seen that when the distance of $V_S - V_R$ is less than 80m,, the achievable rate of NOMA system with imperfect SIC underperforms OMA system when the transmission power is 20dBm. It can be concluded when the transmission power is greater than a certain value and the transmission distance is smaller than a certain value, the achievable rates benefits are jeopardized by the imperfect SIC of NOMA system compared with OMA system.

## 4. Conclusion

In this paper, a NOMA-V2V cooperative communication system model is proposed. The outdated CSI of source-relay and relay-destination V2V links are derived based on two-cylinder channel models. Outage probabilities of NOMA-V2V and OMA-V2V cooperative systems are also derived. The effect of power allocation factors, transmission power, residual interference, and the distance between transmitting and receiving ends on achievable rates and outage probabilities are analyzed for NOMA-V2V and OMA-V2V cooperative systems. The achievable rates of NOMA-V2V and OMA-V2V cooperative systems decreases as the distances between transmitting ends increase. Moreover, when the transmission power is greater than a certain value and the transmission distance is smaller than a certain value, the achievable rates benefits are jeopardized by the imperfect SIC of NOMA system compared with OMA system.

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